GEOPHYSICS, VOL. 49, NO. 8 (AUGUST 1984); P. 1301-1312, 14 FIGS.

Automated interpretation of airborne electromagnetic data

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ABSTRACT

Recent improvements in equipment quality make it possible to increase the usefulness of airborne electromagnetic (EM) systems in areas of moderate electrical conductivity for the purpose of constructing simple electrical property maps which can be related to surficial geology. This application of airborne electromagnetics may be demonstrated and evaluated using Barringer/Questor Mark VI Input® survey results in places where independent verifications of the airborne data interpretation are available.

For this purpose we have developed a set of computer algorithms which read digitally recorded Input data and interpret them automatically in terms of a simple electrical section that is defined by a single conductive layer whose thickness, conductivity, and subsurface depth are determined from the data. Because this technique is formally based on a one-dimensional, three-layer, three-parameter, horizontally stratified earth model, it is only applicable in regions where the surficial formations are mildly dipping and the conductive layer is covered by, and rests on, highly resistive materials.

The interpretation method is illustrated by three field examples. At the first field survey site, in Alberta, Canada, airborne EM survey data are used to map the depth of the interface between coarse and clayey sands. Data from a second survey site, this time in the Western USA, are interpreted to yield the section of a subsurface valley filled with conductive clay. The final example, taken from British Columbia, Canada, involves the mapping of all the three parameters for a weathered volcanic unit.

INTRODUCTION

Because of recent improvements in data quality, airborne electromagnetic (AEM) systems have evolved from their traditional role as reconnaissance tools for detecting discrete conductive zones in areas of high electrical resistivity to the role of active mapping devices in areas where the surficial deposits show a moderate electrical conductivity. The history of this novel application of airborne electromagnetics (AEM) was reviewed by Palacky (1981) in a recent article that showed how results of AEM surveys can guide geologic mapping. Using either time-domain (Dyck et al., 1974) or frequency-domain airborne EM data (Becker and Roy, 1977; Fraser, 1978; Seigel and Pitcher, 1978; Sinha, 1983), it has been possible to compile simplified electrical property maps which can be related to surficial geology. More recently, Sengpiel (1983) showed how frequency-domain data can be used to define the upper surface of a buried conductive pyrite deposit while Whiting (1983) elegantly demonstrated how Input® time-domain data can be interpreted to map the basement contours in a lignite-bearing basin.

Extensive use of the Input system made it possible to obtain data in three areas where the surficial geology was relatively simple and where auxilary geologic information was available. The conductivity of the surficial materials was sufficiently high so that one could expect to map the conductive horizon with at least a moderate degree of accuracy. By comparing the results obtained from the interpretation of the airborne data with geophysical evidence obtained directly on the ground, we were able to evaluate the errors associated with the direct interpretation of AEM data.

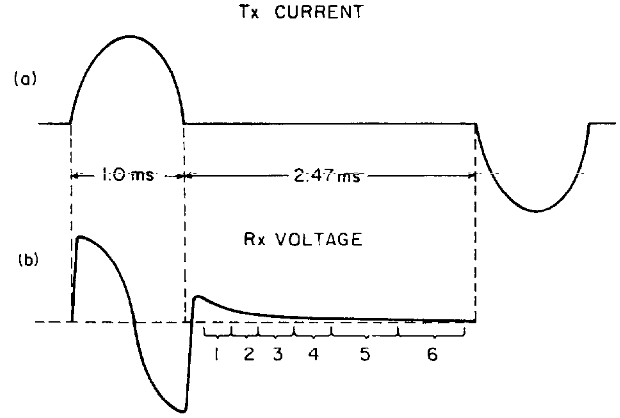

FIG. 1. (a) Primary field waveform for the Input system. (b) Sampling of secondary field.

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SYSTEM DESCRIPTION

The Mark VI Input system is a time-domain AEM apparatus which was described in detail by Lazenby (1973). The transmitter is a large vertical-axis loop attached to the aircraft while the receiver is a small horizontal-axis solenoid that is towed in a bird some 98 m behind and 67 m below the aircraft. The transmitted primary field waveform (Figure 1) consists of a series of half-sine pulses of alternating polarity and 1.0 ms duration. These are separated by a quiescent time of 2.47 ms. The voltage induced in the receiver coil, also shown in Figure 1, is the time derivative of the primary field waveform augmented by the time derivative of the secondary magnetic field. The transient decay of the secondary field is detected by a series of six gates positioned as shown in Figure 1. For our purposes, it was ascertained that the gates were contiguous with the first one beginning at 200 μs after the termination of the primary pulse. Gates 1 and 2 were held open for 180 μs, 3 and 4 were open for 360 μs, and gates 5 and 6 were held open for a time of 540 μs. In order to improve the signal quality, each gated sample is fed to a receiver channel where it is averaged over about 1 s or some 290 repetitions of the primary pulse. While the actual system noise depends upon air turbulence and the atmospheric noise levels, it is always held below 50 ppm on all channels. Finally, in order to correct for any minor drift in the receiver equipment, periodic zero level checks are performed at terrain clearances which ensure freedom from ground conduction effects.

A typical analog Input record containing the EM and terrain clearance data as reconstructed from the digital tape is shown in Figure 2. Channel 6 appears at the top of the record and amplitudes increase downward. One fiducial is plotted every 20 s of flight time which corresponds roughly to a distance of about 1 km.

DATA INTERPRETATION

The model

Because the Input system acquires only six samples of the secondary field transient and because these samples are all located in a limited time window which begins at 200 μs and ends at 2160 μs after the termination of the primary field, it is unlikely that these data can be interpreted in terms of a complex layered section. At best, one can hope to recover a six-parameter model which contains one highly resistive surficial layer and two other layers all of which overlie a conductive half-space. Some initial experimentation with interpreting typical survey data in terms of this large number of parameters, however, quickly indicated that these expectations are unrealistic because of the uniform character of the data. Thus one soon finds that typical data define a layered model well only with a very restricted number of parameters. In particular we have found, as will be shown below, that where the geology may be satisfactorily represented by a simple three-layer model,

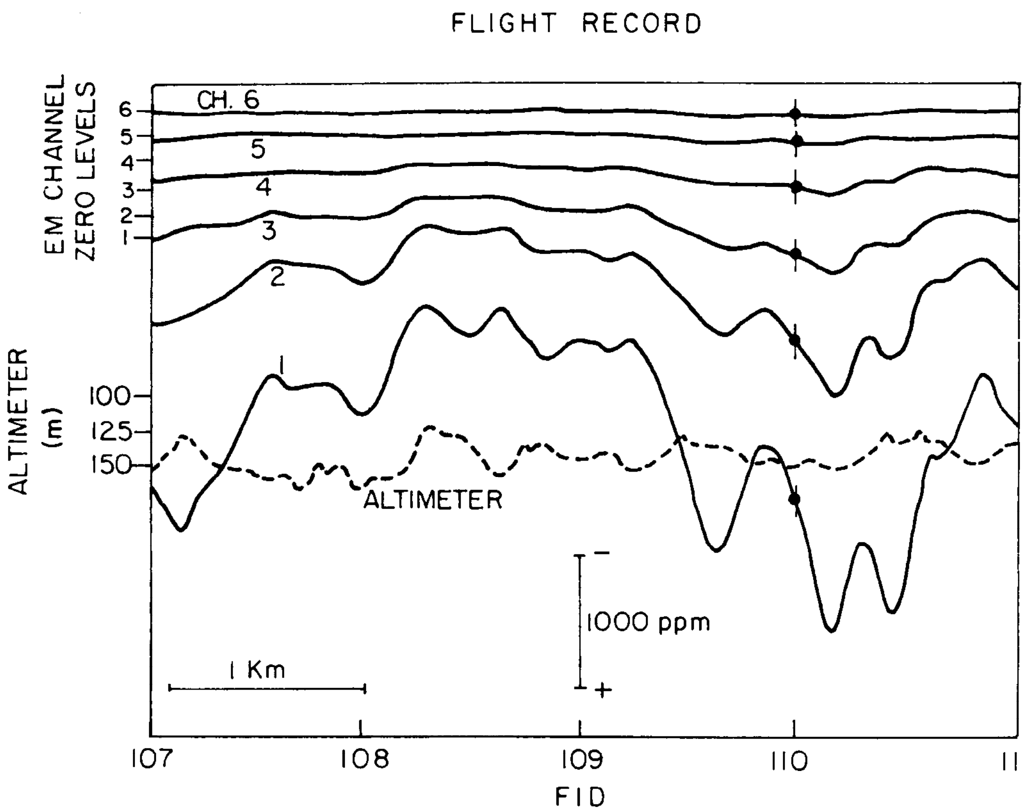

FIG. 2. Typical six-channel Input MK VI data. Record obtained near Smithers, B.C., Canada.

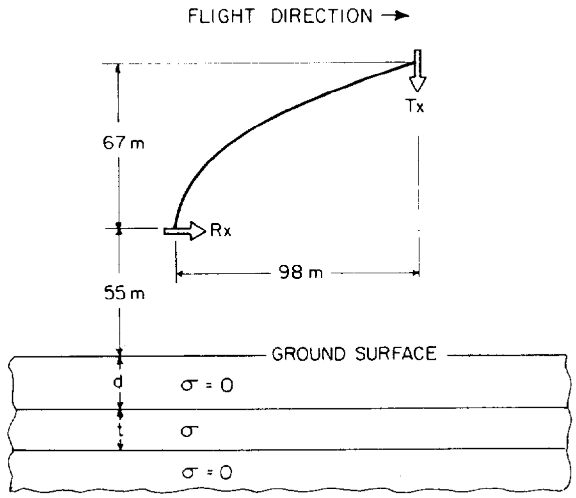

FIG. 3. Simplified three-parameter layered terrain model.

a reasonably correct interpretation can be made of the airborne data. The model we have chosen is shown in Figure 3 and is identical to the one used by Paterson et al. (1982) for the interpretation of frequency-domain helicopter AEM data. Because it is assumed that the uppermost layer as well as the underlying half-space are infinitely resistive, the use of this model is of necessity restricted. Where it is applicable, however, one can expect any satisfactory interpretation method to yield reasonable estimates for the three interpreted quantities, namely, d, the depth to the conductive horizon, σ, the electrical conductivity of the conductive layer, and t, its thickness. When the conductive layer is thin, one can expect its interpreted conductivity and thickness to be highly correlated so that only an estimate of its thickness-conductivity product can be made.

Automated interpretation

In attempting to develop an automatic method of interpretation for Input survey data, we considered some of the least-squares inversion techniques that were recently investigated by Hoversten et al. (1982). We found, however, that application of these methods to areas of any reasonable size (1 km^2 contains about 200 data locations) would prove prohibitively expensive. Instead we elected to use an automated table routine based on a Palacky-West (1973) type of nomogram. As shown in Figure 4, this type of nomogram relates the recorded channel amplitudes representing the secondary field transient to the conductivity and depth below surface (assuming a highly resistive cover) of a specific "three" layer model. The nomogram shown here was originally computed in a mixed system of units, but a conversion scale to metric is included. In the illustration, the thickness of the second layer is very large so that it in fact

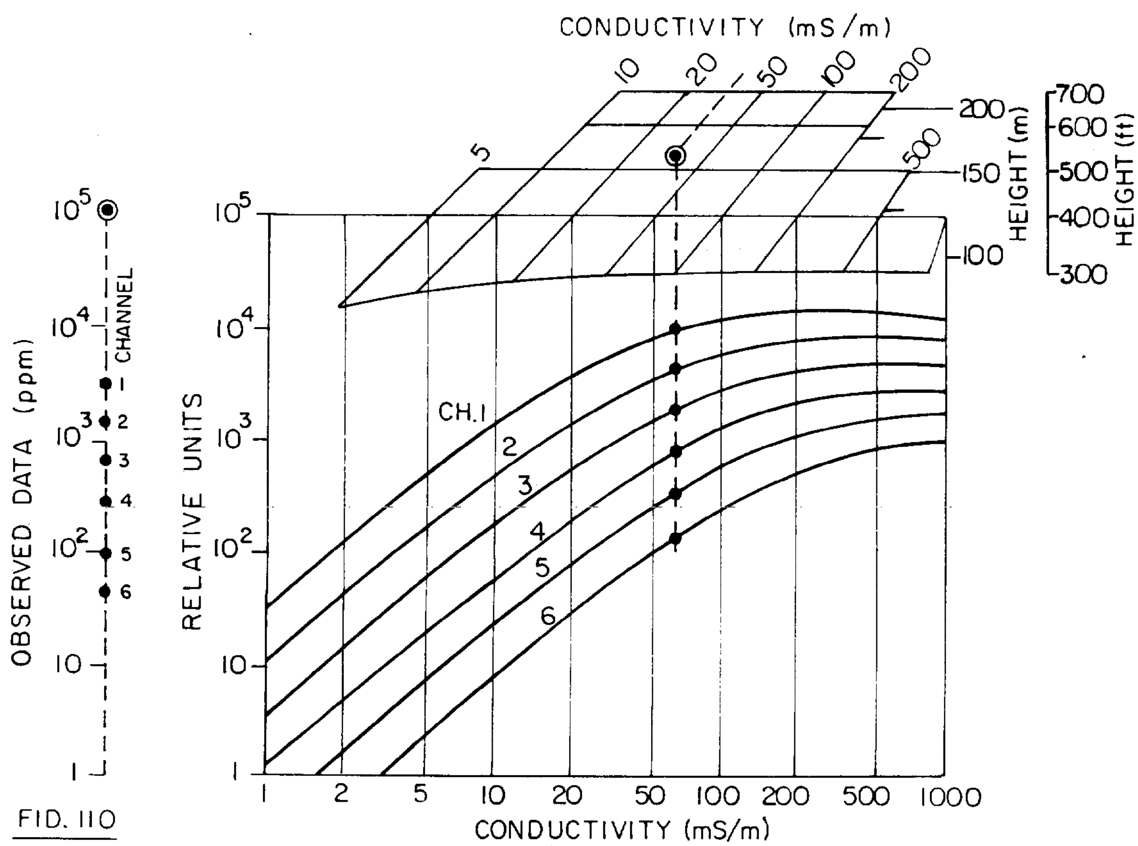

FIG. 4. Palacky nomogram for interpreting conductivity and subaircraft distance for a conductive half-space.

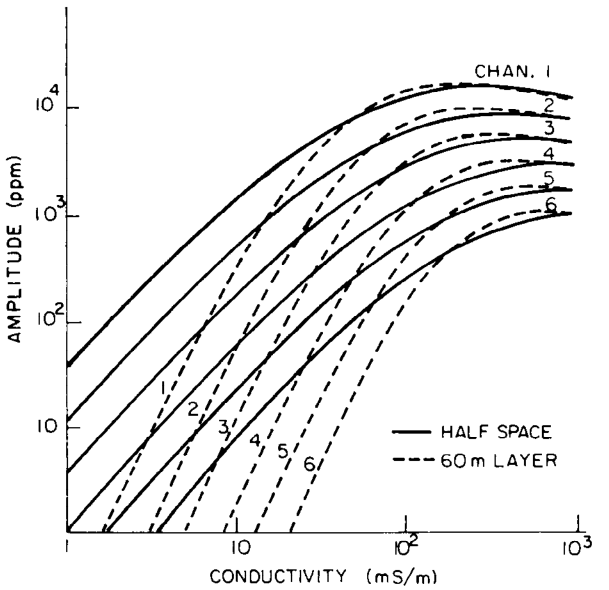

FIG. 5. Comparison of standard Input response for a half-space and a 60 m thick conductive layer. Data computed for a 122 m flight elevation.

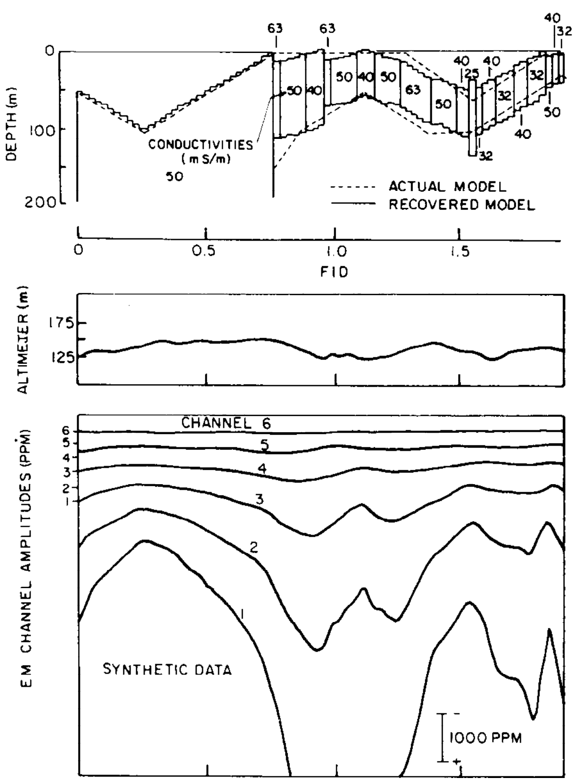

FIG. 6. Interpretation of synthetic data, test 1.

constitutes a conductive half-space. Manual use of such diagrams was discussed by the inventors (Palacky and West, 1973), but for the sake of completeness we briefly illustrate it here. Data at fiducial 110 on the record shown in Figure 2 are replotted in logarithmic format at the left margin of Figure 4. Here, the data point corresponding to channel 1 amplitude is uppermost while the data point corresponding to channel 6 amplitude is lowest. These data are then fitted to the nomogram by vertical and horizontal translation until the data points all fall on the nomogram channel amplitude curves. In the case chosen for illustration, a good fit between the data and the nomogram is obtained for a half-space conductivity of 35 mS/m (millisiemens/meter) and a subaircraft depth of about 160 m. As indicated in Figure 2, the aircraft terrain clearance at fiducial 110 is 152 m so that the thickness of the resistive layer (or the subsurface depth to the conductor) is readily calculated to be 8 m.

It is interesting to note that because the data are transcribed into a logarithmic format, the Palacky-West method principally relates layer conductivity and thickness, or their product, to the transient shape while the depth to the conductive layer is mainly derived from the transient amplitude. For the present purpose, the half-space diagram shown in Figure 4 was part of a set of twelve nomograms, each one corresponding to a different thickness of the conductive layer. It was found that sufficiently good coverage was provided by constructing nomograms at 10-m intervals of conductive layer thickness when this parameter was between 10 and 60 m. For thicknesses between 60 and 160 m, a 20-m interval was used for the nomogram construction.

As shown in Figure 5, the responses for a half-space and a layer of finite thickness, 60 m in the case at hand, resemble each other. These data were computed for the standard coil configuration and an altitude of 122 m. At the upper range of the conductivity scale from 300 to 1000 mS/m the two data sets are quite similar. Below this range, however, the finite thickness of the 60 m layer is readily distinguishable by the lower amplitude and faster decay rate of its secondary field. The numerical calculations associated with the nomogram construction were done as outlined in Becker (1969).

The automated intepretation procedure is based on a sequential attempt at fitting data to each nomogram in the sequence. The process begins with a trial fit to the half-space nomogram and continues sequentially on to the nomograms with lesser thicknesses. As soon as a fit is found for a particular data scan, the process is halted, the interpreted values are associated with the fiducial number for that scan, and the process is then repeated for the next data set. In order to ascertain that a data scan has been satisfactorily fitted to a given nomogram, one evaluates the fit on a root-mean-square (rms) basis using all data for those channels whose amplitude exceeds 40 ppm. The rms fit is calculated both in terms of absolute ppm and relative percent deviations. It appears that reasonable tolerance values for these two quantities are 40 ppm and 4 percent, respectively. If no fit is found between the data and the nomogram suite within the specified tolerance, it is considered that the "three" layer model does not fit the data. Because of the tolerances used and the finite number of tables available, a minor problem has been encountered occasionally when the data fit a particular nomogram but a faulty (negative) subsurface depth is indicated by the data amplitude. If the

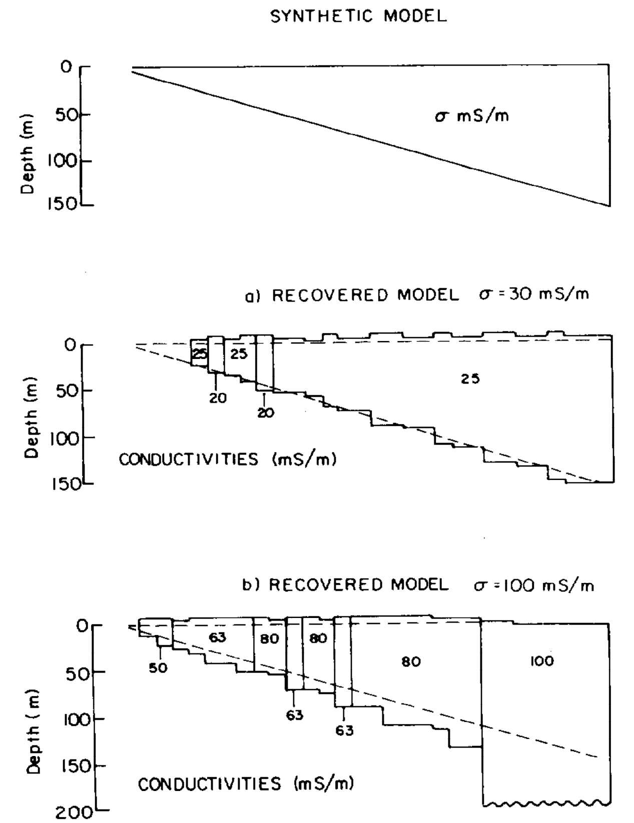

FIG. 7. Interpetation of synthetic data, test 2.

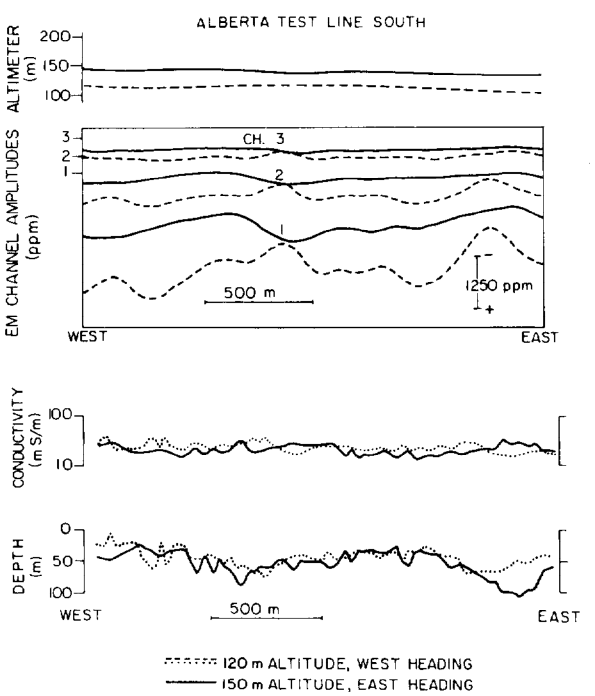

FIG. 8. Process stability as shown by repeated interpretation of two independent data sets.

negative depth is less than 10 m, we consider the top of the conductive layer to be at surface. Models with a negative depth of burial greater than this amount are not accepted.

Synthetic data tests

The automated interpretation routine was first tested on a number of synthetic data sets. One of these is shown in the lowermost part of Figure 6 together with the automatically recovered section. The initial model was a 50 mS/m layer of variable thickness and variable depth of burial. The synthetic data were generated using a juxtaposition of successive one-dimensional (1-D) layered model results. As in practice, a rate of 40 data scans per fiducial was used. The altitude variation effects were incorporated by associating a typical altimeter trace, taken from an actual survey, with the theoretical model. No noise was added to the synthetic data.

In the automated interpretation process we used tolerances of 10 ppm and 1 percent. With noise-free data and close tolerances on fit it appears that this procedure can recover the original model with a reasonable degree of accuracy. Best results were obtained in the case where the quantities to be determined were the conductivity of a half-space and its depth of burial (fids 0.0–0.75). With the exception of the data scan at fid 1.55, it appears that ideally the automated interpretation process can yield thickness and depth estimates accurate to about 15 m and conductivity estimates accurate to about 20 percent. The process breaks down at fid 1.55 where there is a degree of correlation between the layer thickness and its conductivity so that only the layer conductance can be properly estimated.

As shown in Figure 6, errors in layer thickness were greatest in the transition region between the half-space and the finite thickness layer (fid 0.75). In order to investigate this further and in order to evaluate the maximum layer thickness that can be interpreted with the automatic procedure, one can use a simple wedge model as suggested by Paterson et al. (1982). Figure 7 shows the error in estimates of layer thickness for two different wedge conductivities. In this case the synthetic data set was prepared using a constant 122 m aircraft elevation. Tolerances of 40 ppm and 4 percent were used in the model recovery process. As shown in the illustration for the 30 mS/m wedge, good conductivity and thickness estimates can be made up to a layer thickness of 150 m when the layer conductivity is moderate. When the layer conductivity is increased to 100 mS/m, only layer thickness less than 75 m can be correctly estimated. The derived layer thicknesses exceed their true values because the table look-up procedure was initiated on the half-space table.

Process stability

One of the most important features of any data acquisition and interpretation process is its robustness or stability. Thus any procedure which artificially yields very large variations in the interpreted parameters in response to small added noise or minor data variation is unacceptable. The best way to examine the quality of a given process is, of course, through the interpretation of two sets of independent observations.

In our case we were fortunate to secure two independent but collinear Input data sets flown in the vicinity of Fort McMurray, Alberta, Canada. One data set was acquired at a nominal

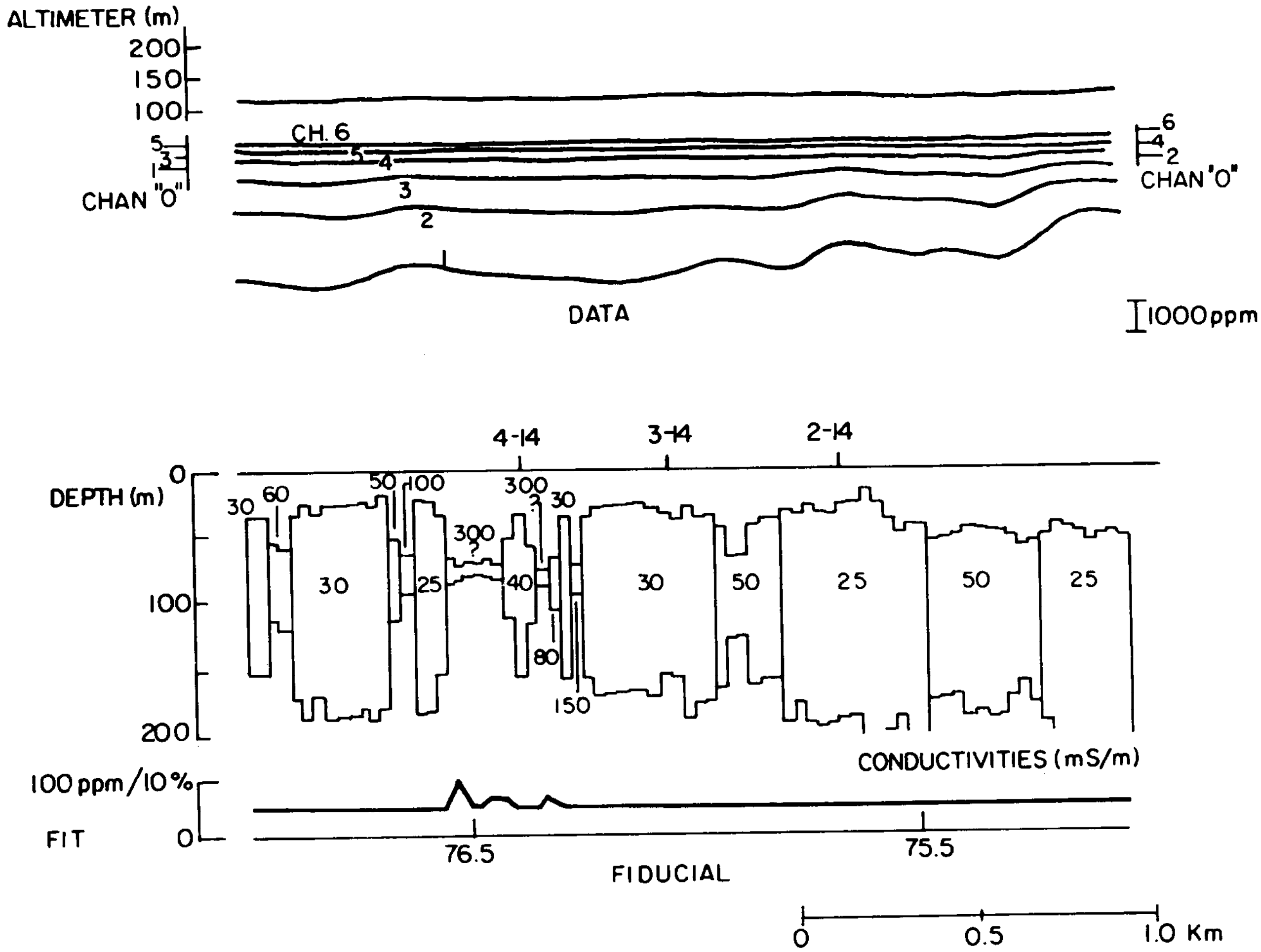

FIG. 9. Typical interpreted section, Fort McMurray area.

altitude for 120 m while the other set was flown on an opposite heading at an altitude of 150 m. The data and the interpretation are shown in Figure 8. Only the first three channels in each data set show any significant response and these are plotted in the upper portion of the illustration. The interpreted parameters are shown in the lower part of the figure. Because the data could consistently be interpreted in terms of a conductive half-space overlain by a highly resistive medium, only the half-space conductivity and the depth to the conductive horizon is shown. The conductivity over the 2 km distance shown was surprisingly uniform and had an average value of about 25 mS/m. The depth to the conductor showed a little more character as it varied from 10 to 110 m. It had an average value of about 50 m.

With the exception of a short section near the eastern end of the profile, it appears that the Input data acquisition process and the proposed method of automated data interpretation are reasonably stable and consistent. The mean differences in the interpreted parameter values for the two independent data sets are of the same order of magnitude (± 20 percent for conductivity; ± 15 m for depth) as the errors indicated for the interpretation method by the synthetic data sets. One can then conclude that the fit tolerances used, i.e., 40 ppm rms absolute and 4 percent rms relative, are consistent with the data quality.

FIELD EXAMPLES

Fort McMurray, Alberta, Canada

This test site is located just east of the Athabasca River and a few kilometers north of the Fort MacKay settlement (57°10′N, 111°40′E). Interest in this area is, of course, stimulated by the presence of massive hydrocarbon reserves associated with the Athabasca tar sands. In fact, the data used in our investigation (Figure 9) were acquired along a flight line that crosses the no. 3 orebody of the Allsands project operated by a consortium of petroleum companies.

The surficial geology in this area is relatively simple (Henderson, 1982). A fairly resistive overburden is composed mainly of sands and gravels (1–10 mS/m) covering the more conductive

(10–40 mS/m) McMurray formation. This member of the column consists of coarse sands, clayey sands, silts, and shales. High-grade tar sands are found in fluvial channels within the upper McMurray. Because the thickness of overburden is an important factor in determining any eventual production costs, much interest has been shown in geophysical methods that can provide useful information on this quantity.

Typical Input data for this area are shown in the upper part of Figure 9; the associated interpreted model profile is shown in the lower part of the figure. Although each data scan has a discrete conductivity value associated with it, we have grouped these about a number of recurring values in order to simplify the presentation. With the exception of a small region in the vicinity of fid 76.5, the data indicate a thin, 40 m layer of sands and gravels covering a substantial (150 m) thickness of the McMurray formation. In the vicinity of fid 76.5 difficulty is experienced in fitting the data to the nomograms at the normal tolerances of 40 ppm and 4 percent, and these must be relaxed to 100 ppm and 10 percent for a fit to be achieved. Even then we do not have stable estimates for the conductive layer parameters. One must observe, however, that even in this possibly complex region, our estimates of the thickness-conductivity product show a very smooth variation about a central value of some 3.3 S.

Figure 9 also shows the position of drill holes 2-14, 3-14, and 4-14. These are shallow holes for which Schlumberger electrical Laterologs® were available. The logs allow us to compare the results of the airborne data interpretation with the electrical parameters as measured in the drill hole.

Let us now consider the results for these holes and two additional drill holes, 14-10 and 2-13, that are located along the same flight line. In Figure 10, the measured data are shown as a solid line while the interpreted parameters are shown in broken line. The resistivities in $\Omega \cdot$ m are plotted logarithmically on the abscissa while the depth is shown in meters along the ordinate. For purposes of comparison, a resistivity of 1000 $\Omega \cdot$ m has been assigned to the resistive unit interpreted from the airborne data. In general, the parameters interpreted from the Input data agree with the Laterolog results. The thickness of the top-most resistive unit, however, appears to be consistently overestimated by amounts as low as 3 m in hole 14-10 to a maximum error of 15 m in hole 2-14. We thus find that our depth estimates seem to be better than 25 percent and are within the accuracy of ± 15 m indicated by the synthetic data analysis. With the exception of hole 2-14, rather good agreement is obtained between the interpreted and measured values for the resistivity of the McMurray formation. No verification could be made of our estimates for the thickness of the conductive layer because the boreholes were not drilled to a sufficient depth.

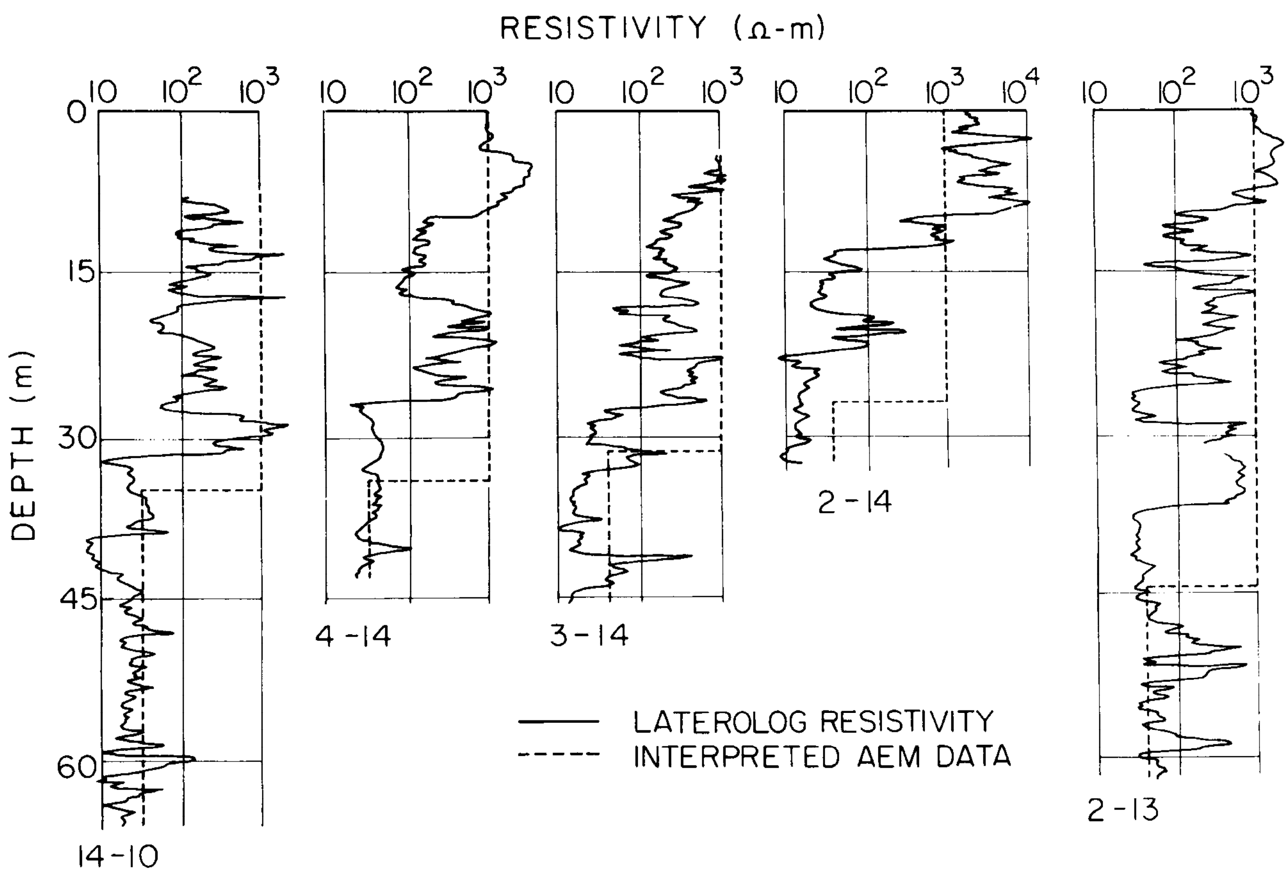

FIG. 10. Comparison of AEM interpretation and Laterolog results.

Western United States

The second field survey test site is located in a Jurassic greenstone belt in the Western United States. The metamorphosed andesitic and basaltic lavas are covered by Tertiary and/or Quaternary formations which include consolidated and unconsolidated clays and sands. It appears that the surficial formations are highly conductive while the basement complex is not. Bedrock topography was of interest here because its features could be helpful in distinguishing between the mafic and siliceous members of the basement complex which differ from each other in weathering rates. Bedrock topography at the test site (S. Bronskill, pers. comm.) was known from a gravity survey which was interpreted to outline a clay-filled valley. Good control for the gravity interpretation was provided by a number of drill holes some of which penetrated bedrock.

Typical survey data for this area and its interpretation are shown in Figure 11. Here the data from flight line 51100 indicate a moderately conductive 25–100 mS/m clay cover whose thickness ranges from 10 to 150 m. The quality of the data fit is moderate with many instances where the tolerance had to be relaxed from its normal 40 ppm and 4 percent values. No interpretation was possible over a small region near fiducial 262 where 60 Hz powerline interference strongly contaminates the data.

Figure 12 compares the bedrock topography interpreted from the Input data with the bedrock profiles as interpreted from the gravity data. Surficial topographic profiles are also indicated and the Input interpretation has been manually adjusted to conform to them by making the points of interpreted conductor outcrop coincide with the known surface profile. The comparison between the two interpretations is made over five parallel flight lines separated by one-half mile. The shape of the conductive valley fill as interpreted from the airborne data is shown in a dashed line, while a solid line represents the known upper surface and the gravity interpretation for the lower surface. Drill holes are indicated by heavy vertical lines. The bedrock shape as interpreted from the Input data correlates well from line to line and shows good agreement with the valley outline defined by the gravity data and drilling results. Along

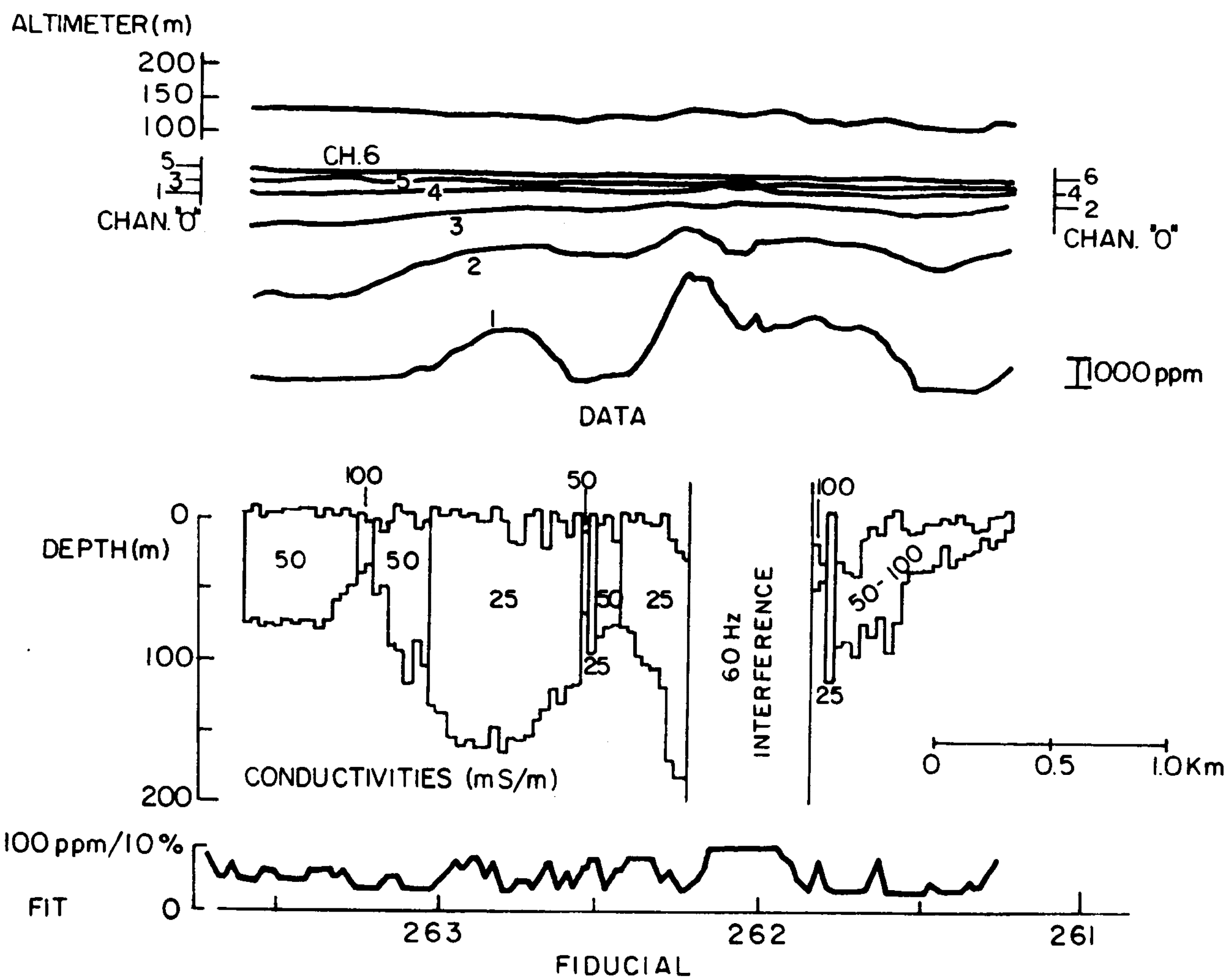

FIG. 11. Typical interpreted section western U.S.A.

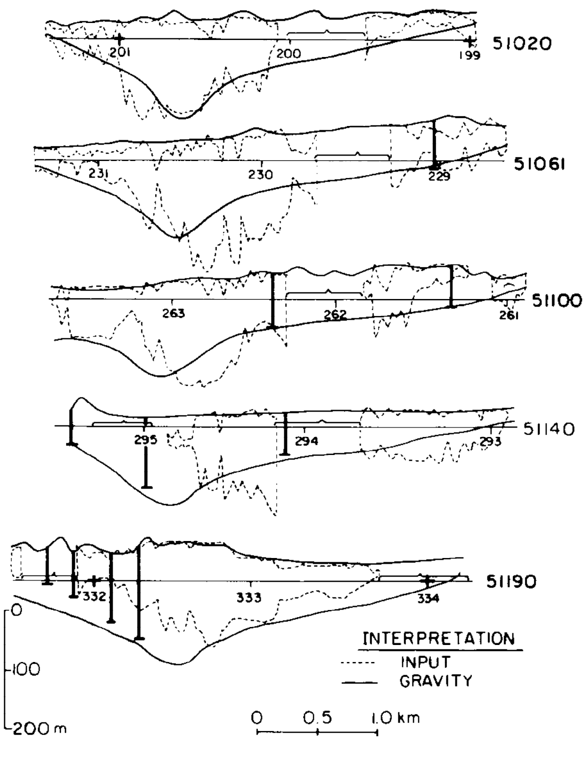

FIG. 12. Comparison of AEM interpretation and ground results, conductive valley fill, western U.S.A.

some segments, such as in the vicinity of fiducial 332 on line 51190, the clay thickness is severely underestimated while along others, such as near fiducial 230 on line 51061, that quantity is highly overestimated. No interpretation was possible along a small segment of each line where the data were corrupted by 60 Hz interference.

Smithers, British Columbia, Canada

There is not much outcrop in this area and little is known about its geology. The major unit here is a variably weathered dacite covered by a 20–50 m thickness of very resistive glacial till. Because of the weathering and perhaps because of its composition, the dacite is fairly conductive. Its unusually low resistivity was directly verified in the field and is responsible for most of the electromagnetic (EM) response in this area. Variations in bedrock topography can cause discrete anomalies in the AEM records and render exploration in this area very difficult. The lack of geologic control in this test region, however, is more than compensated for by the availability of good ground EM data and a limited number of electrical resistivity data. Thus the quality of the Input data interpretation at this test site can be verified by checking for consistency between the airborne data interpretation and the ground results.

Let us first consider a comparison between airborne and ground EM results. This was possible along a short, 700 m, surface grid line which ran at some 30 degrees to the direction of the flight lines. Because of a suspected anomaly in the airborne data, a five-frequency HLEM (Max-Min II) survey was carried out here with a coil spacing of 200 m. The results of the ground survey are shown in Figure 13. As the frequency is raised from 222 to 3555 Hz, the average secondary field is indicative of a typical layered response. Here it is interesting to note the classical phase rotation of the secondary field which is progressively retarded from its initial position in the first quadrant of the Argand diagram to its final position in the third quadrant. In addition to the layered response, the HLEM data set shows a weak discrete anomaly at station 15W.

The typical Input data shown in Figure 2 are derived from this area. When such data are interpreted in the usual manner, one can construct an electrical section beneath the ground traverse line by projecting interpreted data from three adjacent flight lines that intersected the surface line at an angle of 30 degrees. This information and the location of the points of intersection are displayed in the lowest portion of Figure 13 and shows a section dominated by at least a 140 m thickness of weathered dacite overlain by some 15 to 30 m of resistive glacial till. The conductivities in the dominant unit vary between 25 and 60 mS/m.

In order to see whether this interpretation of the Input data was consistent with the ground results, we calculated the theoretical HLEM response values that would be generated by the interpreted section. Once again, a 1-D layered model was used to generate the HLEM results. Figure 13 shows the theoretical data superposed on the measured HLEM field data. In general, the interpreted Input section appears to be correct as the mid-frequency agreement between the measured and theoretical HLEM values is reasonably good. Evidently the AEM-derived data are smoother and lack the detail shown by the ground data. This is particularly true in the vicinity of 15W where the minor ground anomaly is not reflected by the airborne data. Surprisingly, a major positive high-frequency anomaly found in the ground data between 11 and 12W is not reflected in the airborne results. Possibly this feature is of limited areal extent and was missed because of the flight line positioning.

In another region of this test area we had occasion to compare the interpreted Input data with the interpretation of a Schlumberger electrical sounding. Here we found a disagreement between the two data sets in excess of our expectations. In this case the ground data indicated some 30 m of moderately resistive (20 mS/m) drift over a second 20 m thick unconsolidated resistive (5 mS/m) layer. These two layers covered a 90 m section of weathered volcanics whose conductivity was interpreted to be about 95 mS/m. In contrast to these values, and of course assuming zero conductivity for the cover, the airborne data indicated a 40 m thickness for the glacial till and a 50 mS/m conductivity for the weathered bedrock unit. Initially it was difficult to reconcile the difference between the conductivity values assigned by the automatic interpretation method to the bedrock and the high value that was indicated for this formation by the Schlumberger data. Some auxiliary numerical experimentation, however, indicated that this discrepancy can be related to the infinite resistivity that the automatic interpretation method assigns to the uppermost layer. In fact if one allows the uppermost layer here to take on a conductivity of about 10 mS/m, then an excellent fit can be obtained to the airborne data by assigning a value of about 80 mS/m to the bedrock. The depth to the conductive interface does not appear

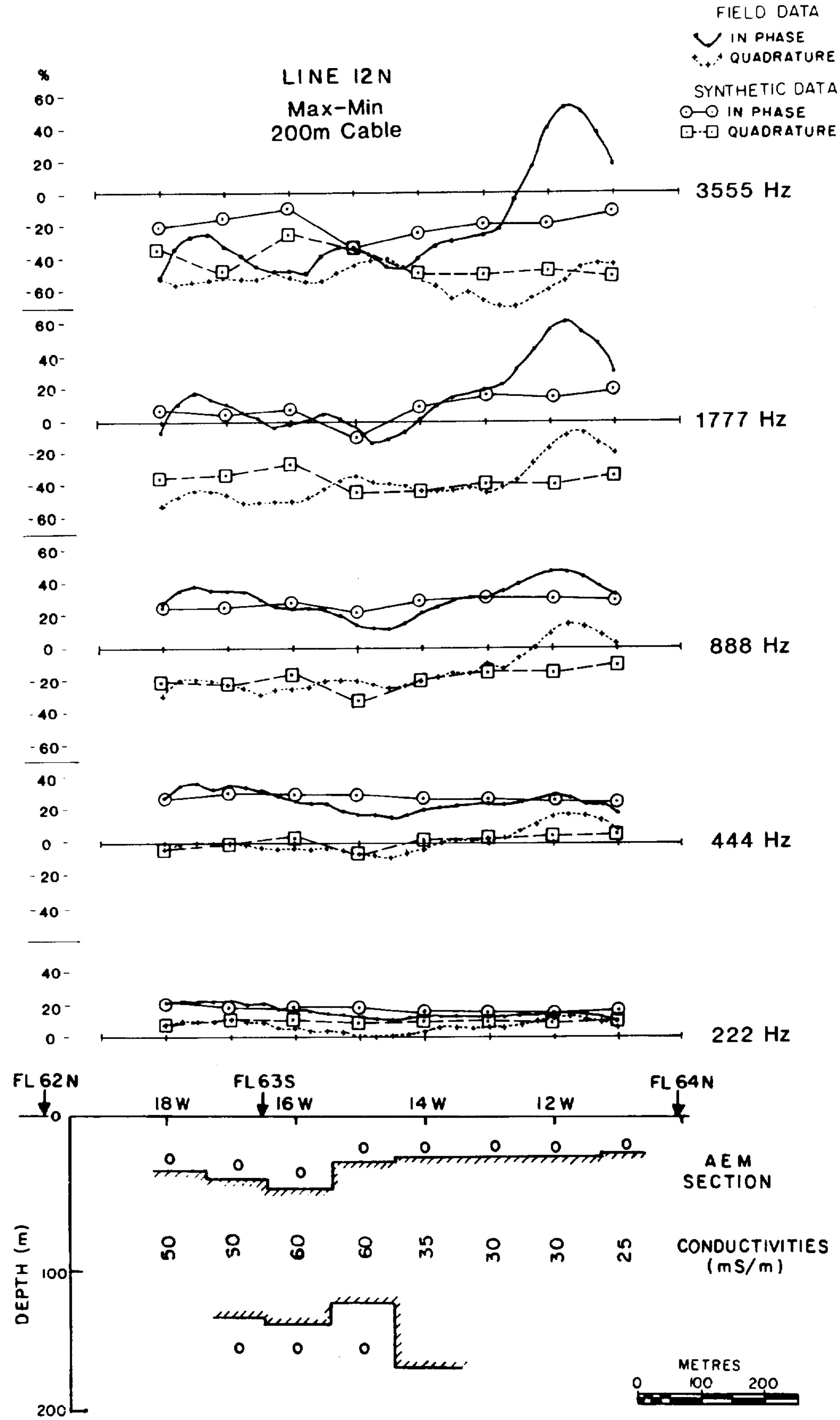

FIG. 13. Comparison of measured and computed HLEM results. Theoretical results based on section interpreted from AEM data.

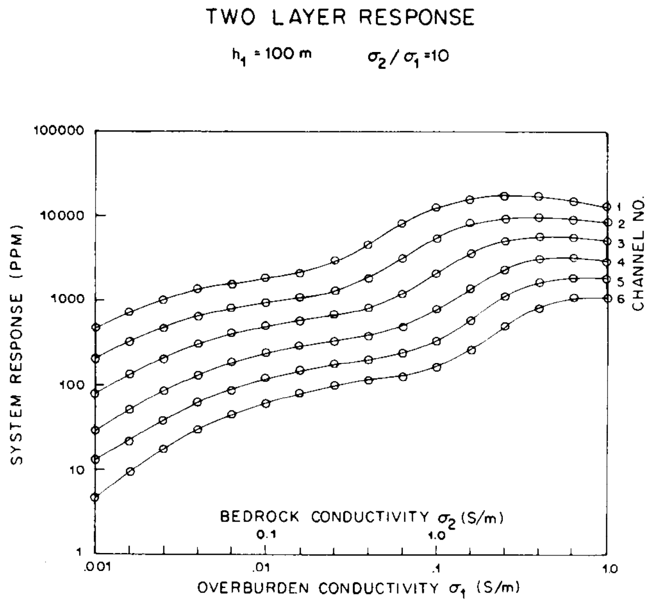

FIG. 14. Input response for a two-layer model with mildly conductive overburden. Data computed for a 122 m flight elevation.

to be much affected by this change in surficial conductivity.

CONCLUSIONS

In many cases, airborne time-domain data can be interpreted to yield useful geologic information. Where the surficial geology is simple enough to be represented correctly by flat-lying formations which follow a resistive, conductive, resistive (type H) sequence with an infinitely resistive surficial layer and bedrock it is possible to devise a method for interpreting the airborne data automatically. The interpretation is done in a noninteractive manner on a digital computer. The process reads the digital data tapes and returns a plot of the simplified geologic section beneath the flight path.

The field examples presented here illustrate the usefulness of interpreting the overburden parameters from the airborne data and support our conclusions regarding the accuracy of the automated interpretation process. Of particular interest on many projects is the estimation of overburden thickness. We were able to demonstrate that this quantity can be fairly reliably determined where the surficial geology conforms to the simple model used as a basis for the interpretation technique. The acquired information can be used for purposes as diverse as estimating the cost of overburden removal in mine planning or geologic mapping by correlating bedrock topography with differential subsurface erosion.

Analysis of synthetic theoretical data shows that the simple automated table look-up method presented here is capable of estimating layer dimensions to about 10–15 m and the conductivity of the conductive member of the column to about 20 percent in a three-parameter model in which both the first layer and the bedrock are assumed to be infinitely resistive. In order to determine the thickness of the conductive layer, as well as its depth and conductivity, the combined thickness of the first and second layers should not exceed 120 m.

As in any other method of data interpretation, this one has its inherent weaknesses. Perhaps the most significant of these is the restriction of its use to a single conductive layer. To illustrate the effects of this assumption for at least one case, we have computed the Input system response for a conductive half-space covered by a 100 m layer of material which is only ten times as resistive as the underlying conductor. The data for this model are shown in Figure 14. Although this diagram is labeled differently (in S/m instead of mS/m), the scales here are the same as those in the half-space nomogram shown in Figure 4. Comparing the two data sets, it can be appreciated that when the overburden and bedrock resistivities are low (less than 25 mS/m for the overburden and 250 mS/m for the bedrock) the two-layer data taken from Figure 14 can be made to fit the half-space nomogram reasonably well. Because of the finite conductivity of the top layer, however, the secondary field amplitudes are larger than those from the bedrock alone. This phenomenon will result in an underestimation by 20 to 50 percent of the depth in the conductive bedrock while the estimates for the bedrock conductivity will be essentially correct. In the mid-range of overburden conductivity, that is between 25 and 250 mS/m, the two-layer data will usually not fit the half-space nomogram. When they almost do, as in the case of 100 mS/m overburden, the use of a half-space nomogram for its interpretation will lead to an underestimation of the overburden conductivity by as much as 30 percent. When the conductivity of the surficial material exceeds 250 mS/m, the effects of the even more conductive bedrock are severely attenuated and the conductivity of the 100 m top layer can be properly interpreted.

Evidently, as suggested by the reviewers, the proposed method of data interpretation can be quite inadequate where the survey area contains sharp near-surface lateral conductivity discontinuities. On the positive side, however, where this condition does not exist one can get good results. Furthermore, in areas where the resistivities of the surficial materials are fairly uniform and known from other work, one should be able to extend the use of the data interpretation method proposed here to the case where one wants to determine the thickness of two surficial layers and the conductivity of the bedrock from airborne time-domain electromagnetic data.

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